Putting TPOs

by Mark S. Graham

TPO single-ply membrane roof systems enjoy widespread acceptance and use in the U.S. roofing industry. According to NRCA's most recent annual market survey, TPO membranes were used in about 10 percent of all low-slope roofing projects (new construction and reroofing), totaling more than $1 billion in installed costs.

Because of the interest in TPO membranes, in 2000, NRCA conducted a laboratory-based research project of TPO membrane products. This research revealed significant differences between some TPO membrane products that were on the market at that time and called for a credible material standard for TPO membrane products. (See "Testing the differences," November 2001 issue, page 22.)

Since then, there have been at least two relatively significant milestones relating to TPO membrane products. First, TPO membrane products have matured in the marketplace and roofing contractors have become more accustomed to and comfortable with using this category of roof membrane products. Second, in 2003, ASTM International published ASTM D6878, "Standard Specification for Thermoplastic Polyolefin Based Sheet Products." This standard provides a consensus-based method for evaluating TPO membrane products.

In 2005, NRCA conducted an additional series of laboratory tests on newly acquired TPO membrane products. Following is an overview and results from this latest testing, as well as additional information that should be useful to users of TPO membrane products.

NRCA testing

NRCA's 2005 testing program of TPO membrane products consisted of obtaining full roll samples of white, 45-mil-thick reinforced TPO membrane products from the open market and testing these products according to ASTM D6878.

The testing's primary purpose was to develop baseline physical property data from which the products' long-term performances can be evaluated. Secondary objectives included determining compliance with ASTM D6878, developing data from which these products can be compared and attempting to determine areas in which ASTM D6878 can be enhanced.

It is important to note the testing was conducted on a limited, defined sample set. The results are representative of only the rolls tested and may not be representative of all TPO products or specific manufacturers' TPO products during a given period. Individual manufacturers have in-house manufacturing quality-control procedures that define how far a single roll of material may vary from their established norm. Because the TPO products included in the testing were obtained from the open market, NRCA had the same opportunity to procure satisfactorily (or unsatisfactorily) performing material as any other procurer of TPO products.

Also, some manufacturers acknowledge changes in their product formulations may affect their products' physical properties. Therefore, the results for the products indicated should not be construed

as being representative of products currently manufactured or manufactured some years ago.

Sampling

For the testing, NRCA obtained nine full rolls of TPO membrane products in their original packaging. The rolls were provided to NRCA by NRCA's technical committee members from throughout the U.S.; committee members purchased the products through typical distribution sources.

NRCA recorded information about the products from the products' packaging and labeling. Also, each roll was unrolled and visually inspected, and any visible product marking was recorded.

Figure 1 provides the sample designation (for testing purposes), manufacturer, product name, package marking and product marking for each TPO product tested.

The TPO membrane products tested include single-roll samples from four manufacturers: Carlisle SynTec Inc., Carlisle, Pa.; Firestone Building Products Co., Indianapolis; GAF Materials Corp., Wayne, N.J.; and Stevens Roofing Systems, Holyoke, Mass. Three rolls of TPO membrane manufactured by GenFlex Roofing Systems, Maumee, Ohio, and two rolls of TPO membrane manufactured by Johns Manville Roofing Systems, Denver, were provided and tested.

Sample A (Carlisle SynTec) and sample E-1 (Johns Manville Roofing Systems) did not include package or product markings that specifically identify the product manufacturers or product names. For the testing, these products have been assumed to be from Carlisle SynTec and Johns Manville Roofing Systems, respectively, based on the delivery tickets and invoices provided. Interestingly, both samples bear similar package and product markings.

Samples D-2 and D-3 (GenFlex) and Sample E-2 (Johns Manville Roofing Systems) also bear some similar package markings and product markings. The item number (Item #MW1404), lot number (Lot #000565) and product marking (565) on each of these products is identical. Samples D-2 and E-2 indicate similar dates (02/17/05), but sample D-3 appears to indicate a manufacturing date that is one day later (02/18/05). These rolls were obtained from distinctly different U.S. regions. Samples D-2 and E-2 are from the eastern U.S., and Sample D-3 is from the West Coast.

Thicknesses

Figure 2 reports the overall thicknesses and thickness-over-scrim measurements for the top and bottom coatings of the membrane samples in an as-received (not exposed weathering) condition. The reported values are averages of at least five measurements uniformly distributed across the rolls' full widths. Overall thickness measurements were taken according to ASTM D751, "Standard Test Method for Coated Fabrics." Thickness of coating-over-scrim (reinforcing fabric) measurements were taken according to the optical method described in Annex A1-Optical Method for Measurement of

Thickness of Coating Over Scrim (Reinforcing Fabric) that is included within ASTM D6878.

For each membrane sample tested, the overall thickness measurements exceed the 39-mil minimum requirement provided in ASTM D6878. Also, for each membrane sample tested, the coating thickness over fabric or scrim, weathering side only, exceeded the 12-mil minimum requirement provided in ASTM D6878.

ASTM D6878 does not provide a minimum coating thickness over fabric or scrim on the bottom side of TPO membrane sheets. A sheet's bottom side

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TPO products analyzed

Designation	Manufacturer	Product Name	Package Marking	Product Marking
A	Carlisle SynTec Inc.	Not labeled	303386 AAW 045 6' x 100' PCKG #9C204B3536002 Date: 11/03/2004	9AAW041103C2
B	Firestone Building Products Co.	UltraPly TPO 96 45-mil white thermoplastic membrane	48" wide x 100' long W56 TPM 3048	11:06 p.m. Firestone 11-04-03
C	GAF Materials Corp.	EverGuard TPO45	White 1/27/2005 TPO 45 mil	MV 012705 2100
D-1	GenFlex Roofing Systems	GenFlex TPO White TPO	Product #M10004 Work Order #4794 Dimensions: 0.45 x 4' x 100' Color: White Date: 09/10/02	4794
D-2	GenFlex Roofing Systems	GenFlex TPO (White)	.045 x 4' x 100' Item #MW1404 Lot #000565 02/17/05 Serial #39447	565
D-3	GenFlex Roofing Systems	GenFlex TPO (White)	.045 x 4' x 100' Item #MW1404 Lot #000565 02/18/05 Serial #39677 565	565
E-1	Johns Manville Roofing Systems	Not labeled	300425 AAW 045 4' x 100' PCKG #9C30357N46002 Date: 05/07/2003	9AAW030415B1
E-2	Johns Manville Roofing Systems	UltraGuard TPO SRT-45 FR	Item #12722335 Color: White Dimensions: 4' x 100' Weight: Approx. 84 lbs MW1404 Lot #000565 02/17/05 Serial #39446	565
F	Stevens Roofing Systems	Stevens EP (TPO)	2026927 SRW1161 045 52.5 WH/GN-100' FG Roll: 49630004007 Operator: ED Shift: 2 Cal Date: K134 Splices: 0 Sqr Ft: 437.50 (SqM 40.46) Comment:	EP K1804

Figure 1: Descriptions of the TPO products analyzed

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is the mating surface in heat-welding field seams that is critical in allowing for proper application. For each sample tested, the minimum coating over fabric or scrim at the bottom side of the membrane exceeds ASTM D6878's minimum requirement for the top side (exposed to weather); however, for seven of the nine samples, the bottomside coating thickness is less than the topside coating thickness. Sample B exhibits a bottomside coating thickness greater than its topside coating thickness. Sample F exhibits equal topside and bottomside coating thicknesses.

Thickness values for tested membranes

Designation	Overall Thickness (inches)	Thickness over scrim (inches)	
		Top	Bottom
A	0.044	0.023	0.016
B	0.044	0.019	0.020
C	0.044	0.021	0.017
D-1	0.042	0.019	0.018
D-2	0.043	0.018	0.014
D-3	0.042	0.017	0.015
E-1	0.043	0.023	0.016
E-2	0.043	0.017	0.016
F	0.042	0.017	0.017
ASTM D6878	0.039 (minimum)	0.012 (minimum) weathering side	

Note: Inches can be converted to millimeters by multiplying inches by 25.4.

Figure 2: Overall thickness and thickness-over-scrim measurements for tested membranes

Breaking strength

In Figure 3, the breaking strength and elongation at reinforcing break for each membrane as received and after heat aging (artificial weathering) is shown. The results are reported in the machine direction (MD) and cross machine direction (XMD), which is across a roll's width. Breaking strength values are reported in pound force (lbf) units, and elongation is expressed as a percentage.

Breaking strength and elongation at reinforcement break testing was conducted according to Procedure A—Grab Test Method defined in ASTM D751 with a gage length of 3 inches and a crosshead speed of 12 inches per minute. As-received samples were tested at standard laboratory conditions (73.4 F plus or minus 3.6 degrees Fahrenheit and 50 percent plus or minus 5 percent relative humidity). Heat-aged samples were tested at standard laboratory conditions after heat aging for 670 hours at 240.8 F.

For each sample, the breaking-strength values exceed the 220-lbf minimum requirement in ASTM D6878. Similarly, the elongation-at-reinforcement-break values exceed the 15 percent minimum requirement.

In addition, each sample's breaking-strength and elongation-at-reinforcement-break values exceed the minimum 90 percent retained values requirement in ASTM D6878.

Tear strength

Figure 4 reports the tear strength for the samples as received and after heat aging. The samples were tested and are reported in the MD and XMD.

Tear-strength testing was conducted according to Procedure B-Tongue Tear Method defined in ASTM D751 with 8- by 8-inch specimens and a crosshead speed of 2 inches per minute. As-received samples were tested at standard laboratory conditions, and heat-aged

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Breaking-strength and elongation-at-reinforcement-break values for tested membranes

Designation	As received				Heat aged			
	Breaking strength (lbf)		Elongation at reinforcement break (percent)		Breaking strength (lbf)		Elongation at reinforcement break (percent)	
	MD	XMD	MD	XMD	MD	XMD	MD	XMD
A	334	289	27	26	316	291	29	30
B	353	321	31	33	358	333	32	34
C	326	297	34	29	322	301	36	32
D-1	330	302	25	25	348	327	25	26
D-2	292	266	31	31	325	289	33	30
D-3	301	256	33	30	338	290	34	30
E-1	346	323	28	28	332	309	33	32
E-2	296	271	30	30	319	286	32	30
F	334	287	27	32	332	286	29	34
ASTM D6878	220 (minimum)		15 (minimum)		90 percent minimum retained value			

Note: "lbf" can be converted to Newtons (N) by multiplying lbf by 4.448.

Figure 3: Breaking strengths and elongation at reinforcement breaks of tested membranes

Tear-strength values of tested membranes				
Designation	As received (lbf)		Heat aged (lbf)	
	MD	XMD	MD	XMD
A	a	91	a, b	b
B	a	79	a	83
C	a	72	a	90
D-1	a	93	a, b	b
D-2	a,b	b	b	b
D-3	a,b	b	a, b	b
E-1	136	65	a, b	b
E-2	a,b	b	b	b
F	a,b	103	a, b	b
ASTM D6878	55 (minimum)		60 percent minimum retained value	

"a" denotes membrane sample specimens that tore perpendicular to the original cut.

"b" denotes membrane sample specimens that did not exhibit a tearing-type failure (specimen primarily exhibited pull-out of the reinforcement from the coating).

Note: "lbf" can be converted to Newtons (N) by multiplying lbf by 4.448.

Figure 4: Tear strength of tested membranes

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samples were tested at standard laboratory conditions after heat aging.

The test results for Sample E-1 in the MD and samples A, B, C, D-1 and F in the XMD exceed the 55-lbf minimum requirement in ASTM D6878.

For the heat-aged samples, samples B and C in the XMD exceed the minimum 60 percent retained value requirement in ASTM D6878.

For each sample, as received and after heat aging, reliable test results could not be obtained in either MD or XMD or both because specimens tore perpendicular to the original cut or the specimens did not exhibit a tearing-type failure (specimens primarily exhibited pull-out of the reinforcement from the coating).

Membranes' brittleness points	
Designation	Brittleness point
A	-40 F
B	-47.2 F
C	-47.2 F
D-1	-40 F
D-2	-40 F
D-3	-47.2 F
E-1	-43.6 F
E-2	-47.2 F
F	-40 F
ASTM D6878	-40 F

Figure 5: Brittleness point of tested membranes

Brittleness point

Figure 5 reports the brittleness point for the samples tested in an as-received condition. Brittleness-point testing was conducted according to Test Method B from ASTM D2137, "Tests Methods for Rubber Property—Brittleness Point of Flexible Polymer and Coated Fabrics."

The brittleness-point values meet or exceed the -40 F minimum requirement in ASTM D6878 for each sample.

Dimensional change

The linear dimensional changes for the samples tested in an as-received condition are shown in Figure 6.

Linear dimensional change testing was conducted according to ASTM D1204, "Test Method for Linear Dimensional Changes of Nonrigid Thermoplastic Sheeting or Film at Elevated Temperature," after six hours of conditioning at 158 F plus or minus 3.6 degrees Fahrenheit.

Each sample had a linear dimensional change value less than the 1 percent maximum allowable requirement in ASTM D6878.

Water absorption

Figure 7 shows the water absorption for the samples in an as-received condition.

Water-absorption testing was conducted on the topside coating only according to ASTM D471, "Test Method for Rubber Property-Effect of Liquids," after conditioning for 166 hours at 158 F.

The results ranged from 0.02 kg/m^2 to 0.04 kg/m^2. This test is conducted using metric units. ASTM D6878 indicates a 3 percent maximum allowable value by mass for water absorption. Neither ASTM D471 nor ASTM D6878 specifically indicates how the units from ASTM D471 are converted to the percentage defined in ASTM D6878. Therefore, we are unable to determine whether the samples comply with the 3 percent maximum requirement in ASTM D6878.

Analyzing the results

The results from the 2005 testing of TPO membrane products reveal all the membrane samples tested generally appear to comply with the physical property requirements of ASTM D6878.

However, two tests contained within ASTM D6878 were not conducted by NRCA.

ASTM D6878 includes a test requirement for factory-seam strength. Because none of the TPO membrane products evaluated in the 2005 testing appear to contain factory seams, this particular test was not conducted on the TPO membrane samples.

Also, ASTM D6878 includes requirements for weather resistance after accelerated weathering using a Xenon-arc weatherometer according to ASTM G151, "Practice for Exposing Nonmetallic Materials in Accelerated Test Devices that Use Laboratory Light Sources," and ASTM G155, "Practice for Operating Xenon Arc Light Apparatus for Exposure of Non-metallic Materials." Because these tests are relatively costly to perform and, in NRCA's opinion, the test parameters included in ASTM D6878 are not stringent enough to have these tests be a controlling factor, NRCA did not conduct the weather-resistance test.

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The results from the breaking-strength, elongation-at-reinforcement-break and tear-strength tests reveal these specific tests appear to be largely evaluating the performance of a membrane's reinforcement and not a membrane's composite (reinforcement and topside and bottomside coatings).

Improving ASTM D6878

Based on NRCA's 2005 testing of TPO membrane products and its earlier testing of TPO products in 2000, NRCA recommends several changes to ASTM D6878 be considered.

First, NRCA recommends the minimum coating thickness over fabric or scrim be increased from the present value of 12 mils to at least 15 mils. The 12-mil value originally was included in the ASTM standard because several manufacturers claimed to be manufacturing TPO membrane products with 12-mil topside coating thicknesses.

Review of NRCA's 2006-07 *Low-slope Roofing Materials Guide* reveals no manufacturer currently is representing anything less than a 15-mil-thick topside coating. NRCA's 2000 and 2005 testing appears to confirm these manufacturers' representations. NRCA believes a 15-mil minimum topside coating is necessary to allow for proper field lap seaming by experienced applicators. Also, a 15-mil value is the minimum established by ASTM for EPDM and PVC products.

NRCA also recommends a minimum coating over fabric or scrim thickness on the bottom side of a TPO membrane sheet be considered. Bottomside coating thickness is an important consideration in field seaming TPO membrane products because a field-seaming operation involves the hot-air welding of the bottomside coating of one sheet membrane to the topside coating of an adjacent sheet membrane. Data from NRCA's 2000 and 2005 testing indicate a 12-mil thickness would be appropriate; however, NRCA recommends a 15-mil value be considered.

Dimensional change of tested membranes

Designation	MD (percent)	XMD (percent)
A	-0.18	-0.14
B	-0.13	-0.10
C	-0.20	-0.06
D-1	-0.19	-0.07
D-2	-0.35	-0.03
D-3	-0.38	-0.02
E-1	-0.12	-0.04
E-2	-0.37	-0.03
F	-0.16	-0.12
ASTM D6878	±1 (maximum)	

Figure 6: Linear dimensional change of tested membranes

NRCA recommends the tear-strength test method be re-evaluated in an attempt to address the failures related to perpendicular tear and reinforcement pull-out NRCA observed in its 2000 and 2005 testing programs. These types of failures do not appear to be representative of TPO membrane product performances in the field.

Consideration should be given to changing ASTM D6786's heat-aging and weather-resistance testing requirement to more stringent conditions that will clearly evaluate the overall performance of the membrane composite (reinforcement and topside and bottomside coatings).

Although ASTM D6878's heat-aging requirement of 670 hours at 240.8 F is consistent with that of EPDM membrane products as defined by ASTM D4637, "Standard Specification for EPDM Sheet Used in Single Ply Roof Membrane," it differs from the requirement for PVC and KEE membrane products as defined by ASTM D4434, "Standard Specification for Poly(Vinyl Chloride) Sheet Roofing," and ASTM D6754, "Standard Specification for Ketone Ethylene Ester Based Sheet Roofing," respectively.

ASTM D4434 and ASTM D6754 base their heat aging on 176 F plus or minus 4 degrees Fahrenheit for 56 days plus or minus 2 hours. Similarly, the weather-resistance test parameters used in ASTM D6878 are known to not replicate the type of normally anticipated deterioration TPO membrane products experience during in-service field exposure and aging. Consideration should be given to enhancing the test parameters or using alternative test methods that more closely replicate field conditions.

Membranes' water absorption

Designation	Change in mass per unit surface area (kg/m²)
A	0.02
B	0.02
C	0.03
D-1	0.02
D-2	0.04
D-3	0.03
E-1	0.02
E-2	0.03
F	0.02
ASTM D6878	± 3.0 percent (maximum)

Note: This test only is conducted in kg/m².

Figure 7: Water absorption of tested membranes

Closing thoughts

NRCA's 2005 testing of TPO membrane products provides some useful information regarding the compliance of various manufacturers' TPO membrane products with ASTM D6878. It also provides some physical property data that can be used for comparing products.

Also, NRCA's 2005 data, along with the data developed from its 2000 testing, provides for a compelling combined data set that should be useful when evaluating the long-term field performance of TPO membrane products. This combined data also provides a basis for recommending revisions to ASTM D6768.

If you are selecting a TPO membrane product for a particular roofing project, NRCA recommends decisions be based on your experience and the reputation of specific manufacturers for product performance and customer service and response.

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